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USE OF GENITIC ALGORITHM AND PARTICLE SWARM OPTIMISATION METHODS FOR THE OPTIMAL CONTROL OF THE REACTIVE POWER IN WESTERN ALGERIAN POWER SYSTEM

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Abstract

This paper describes the methodology adopted for controlling the reactive power in western Algerian power system. This Algerian system is in phase of extension because of the strong increase of the request of electricity (+ 5 in 7 % a year), With a population increasing by 1.2 % a year, and which changes these consumer habits using a large number of modern electrical equipments. Our objective is to study this system and to try to solve these problems by the optimization of the reactive powers through Felexible AC Transmission System devices and metaheuristics methods of optimization. Several metaheuristics algorithms have been developed based on Genetic Algorithm approach and the swarm intelligence. Those algorithms try to prove their effectiveness in minimizing the power losses, subject to satisfying system constraints like voltage levels, real and reactive power flow on transmission lines, transformer tap settings and switching of discrete portions of inductors or capacitors.

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Keywords: Optimal Power Flow, Power Loss Minimization, Genetic Algorithm, Particle Swarm Optimization, Static VAR Compensator.

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1. Introduction

OPF is a non linear programming problem, used to determine optimal outputs of the generators, bus voltage and transformer tap, setting in power system, with an objective to minimize the active power losses.
The electrical energy is produced at the same time as it is consumed; thus, permanently, the production has to adapt itself to the consumption. It is necessary, thus, to adjust the active and reactive power of generators interconnected in an electrical network in their acceptable limits, and maintaining the entire electrical network under stable tensions. It is called the optimal power flow OPF.
Several methods have been employed to solve this problem, Gradient base, Linear programming method and Quadratic programming; however all of these methods suffer from main problems:
Unfortunately, these methods cannot always supply the optimal solution and do not manage to escape from local optima. Besides, all these methods require the continuity and/or the derivability of the objective function what is not always possible in the practice.
Métaheuristics constitutes then a strategy of more and more favored resolution because they are methods with big flexibility of use. They have the possibility of finding solutions in most large numbers of possible cases.
In this work, to solve the OPF problem and the control of the tension, two methods métaheuristique were used. The first method is the of Genetic Algorithm method [1] and the second one is the Particle Swarm Optimisation method [2], the choice of these methods has for perspective to demonstrate the efficiency of the artificial intelligence application in the field of the planning and the security of electrical networks.

Nomenclature

GA	Genetic Algorithm
PSO	Parcticle Swarm Optimisation
SVC	Static VAR compensator
FACTS	Flexible AC Transmission System

2. Formulation of problem

The objective of our work is the minimization of the total active losses of transmission, and the preservation of the tensions in their allowed limits while satisfying a set of constraints equalities and disparities using metaheuristics methods and FACTS devices [3,4]. Mathematically, this is a stated as follows:

2.1. The objective function

This function is to minimize the active losses and can be expressed by:

$$Min: P_L(V_i, \theta_i) \tag{1}$$

The minimisation problem is subjected of the following equality and inequality constraints:

2.2. Equality constraints:

$$\Delta P_j = \sum_{j=2}^{n} V_i.V_j(G_{ij}.\cos\theta_{ij} + B_{ij}.\sin\theta_{ij}) - P_i^g + P_i^c = 0 \tag{2}$$

$$\Delta Q_j = \sum_{j=2}^{n} V_i.V_j(G_{ij}.\sin\theta_{ij} + B_{ij}.\cos\theta_{ij}) - Q_i^g + Q_i^c = 0 \tag{3}$$

2.3. Inequality constraints:

$$Q^g_{i,\min} \le Q^g_i \le Q^g_{i,\max} \qquad i = 1, \dots\dots\dots n_g \tag{4}$$

$$a_{i,\min} \le a_i \le a_{i,\max} \qquad i = 1, \dots\dots\dots n_T \tag{5}$$

$$V_{i,\min} \le V_i \le V_{i,\max} \qquad i = 1, \dots\dots\dots n \tag{6}$$

$$Q^{sh}_{i,\min} \le Q^{sh}_i \le Q^{sh}_{i,\max} \qquad i = 1, \dots\dots\dots n \tag{7}$$

Avec :

$$P_L = \sum_i^n \sum_j^m -G_{ij}(V_i^2 + V_j^2 - 2V_iV_j.\cos\theta_{ij}) \tag{8}$$

where :

n_g : Number of generator buses.

n_T : Number of tap-setting transformer branches.

n : Number of branches in the system.

a : Transformers tap setting limit.

P_i^g, Q_i^g : Active and reactive powers generated in the bus i .

P_i^c, Q_i^c : Active and reactive powers of load in the bus i.

$\theta_{ij} = \theta_i - \theta_j$: Voltage angle difference between bus i and j.

B_{ij} : Susceptance between the bus i and j.

G_{ij} : Self- conductance between the bus i and j.

3 .Genetic algorithm

GA is widely used in power system. Its strong point is that it has no differentiable constraint, and easy to realize the pursuit of optimum solutions from overall situation. But the experiment shows that variety of individual is falling as the colony's evolving, easy to get locally optimal solutions, and the local searching ability is weak.
The GA is a stochastic search technique that leads a set of population in solution space evolved using the principles of genetic evolution which starts with random generation of initial population and then the selection, crossover and mutation operations are preceded until the fitness function converges to a maximum or the maximal number of generations is reached.

3.1. Selection

Selection is an essential component of GAs, playing an important role especially in solving hard optimization problems. The selection consists in selecting an individual within the population then in copying out him in the new population. The selection is made by means of a function of adaptation (fitness function) which is calculated for every individual of the population. The probability to reproduce or to select an individual depends directly on the value of its objective function.

3.2. Crossover operation

Crossover is a recombination operator. Its objective is to enrich the diversity of the population by treating the components of the individuals (chromosomes). Crossover basically combines substructures of two parent chromosomes (P1, P2) to produce two children (E1, E2). Thus two solutions more adapted. The good strings created by crossover will be next mating by the reproduction operator.

3.3. Mutation

Mutation will take place after performing the crossover[8,6]. The offspring resulted from crossover are randomly changes by operation of mutation. The mutation plays a double role: make a local search and assures besides search as global as local, according to the weight and the number of the bits moved furthermore, they guarantee mathematically that the global optimum can be reached. A typical simple genetic algorithm is described in detail in [5,6]

4. Particle Swarm Optimization

The optimization by particle swarm (PSO) was born in 1995 in the United States under the name of Particle Swarm Optimization (PSO) [7]. This algorithm is inspired by the big groupings of animal's behavior such as the thick clouds of birds, shoals of fish and the swarms of locusts. A swarm consists of a set of particles, where every particle represents a potential solution and is endowed with certain capacities:

- Able to estimate the quality of its position and of keeping in memory its best performance, Can consult its congeners (the closest) and to obtain from each of them its own better position,
- Can choose the best of the best positions knowledge of which it has,
- Also having a random speed and she can modify this speed according to this information and to its own data and moves as a consequence.

The basic algorithm of the PSO can be easily formulated and programmed. Particles are randomly distributed in the space of search for dimension D, and each of them has its own position x_i^k and its speed in the iteration k. Each particle remembers its own better position found until now in the exploration. This position is called better staff and it is indicated by $pbest_i$ in the equation (9). The basic concept of PSO technique lies in accelerating each particle towards its p_{best} and g_{best} locations at each time step.

Besides, among these p_{best}, there is only one particle which has the best position, called the best global, which is indicated by g_{best} in the equation (9).

The modified velocity of each particle can be computed by using the current velocity and the distance from p_{best} and g_{best} according to (9). The positions are modified using (10).

$$v_{id}^{k+1} = w^k.v_{id}^k + c_1.rand_1.(pbest_{id} - x_{id}^k) + c_2.rand_2.(gbest_d - x_{id}^k) \tag{9}$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \tag{10}$$

Where:

rand1, rand2: uniformly random numbers between 0 and 1.

v_{id}^k : Current velocity of individual i in dimension d at iteration k.

v_{id}^{k+1} : Velocity of individual i in dimension d at iteration k+1.

$v_{id}^{\min} \le v_{id}^k \le v_{id}^{\max}$: Maximum and minimum velocity.

x_{id}^k : Current position of individual i in dimension d at iteration k.

x_{id}^{k+1} : position of individual i in dimension d at iteration k+1.
$pbest_{id}$: dimension d of the pbest of individual i.
$gbest_d$: dimension d of the gbest of the swarm.
c_1 and c_2 : the weighting of the stochastic acceleration that pull each particles towards pbest and gbest (cognitive and social acceleration constant respectively).
w^k: inertia weight factor that controls the exploitation and exploration of the search space by dynamically adjusting the velocity and it is computed using (11).

$$w^k = w^{\max} - \frac{w^{\max} - w^{\min}}{iter^{\max}} * iter \tag{11}$$

$iter^{\max}$: Maximum number of iterations;
$iter$: Current iteration number;
w^{max} : Maximum inertia weight;
w^{min} : Minimum inertia weight.

The particle velocity is limited by the maximum value $v^{\max}$. The maximum velocity is characterized by the range of the ith parameter and is given by (12).

$$v_i^{\max} = \frac{U_i^{\max} - U_i^{\min}}{N} \tag{12}$$

Where, N is a chosen number of intervals in the ith parameter.

5. Illustration

To demonstrate the effectiveness of the proposed GA and PSO methods to control reactive power system, the practical western Algerian transmission/ subtransmission system 400/220/60 Kv constituted by 102 bus system are used. This system has 119 load, 14 transformer, 92 load buses and 10 generators buses. The GA-based and PSO algorithms were implemented in MATLAB programming language.

Four different cases were considered to show the effectiveness of the proposed methods
Case 1: Base case Fast decoupled load flow with Qsh and without SVC
Case 2: Base case Fast decoupled load flow with SVC
Case 3: Results of the PSO method without SVC
Case 3: Results of the GA method with SVC

Table .1. Western Algerian electrical network data

Loads buses	92
Generators buses	10
Loads	119
Transformers	14
SVC's	3

Table .2. Limits of the control variables

	Minimal values	Maximal values
v_i	0.9	1.1
a_i	0.9	1.1
Q_{svc}	-40	10
Q^g_1	-170	350
Q^g_6	-240	270
Q^g_{12}	-60	100
Q^g_{13}	-90	180
Q^g_{20}	-80	400
Q^g_{22}	-35	60
Q^g_{24}	-80	400
Q^g_{39}	-15	48
Q^g_{51}	-8	38
Q^g_{55}	-20	30

Table .3 .The parameters of the genetic algorithm selected for the program

Maximum generation	Population size	Probability of crossover (Pc)	Mutation probability (Pm)
120	30	0.9	0.005

Table .4 . The parameters of particle swarm optimization selected for the program

Maximum generation, D	Maximum inertia weight	Minimum inertia weight	Inertia coefficient $c_1=c_2$	Max iteration number
200	0.9	0.4	1.5	509

This optimization consists in controlling the reactive power, the buses voltages are determined fig .1.2.3 and 4, as well as the values of the minimal losses in the network between the four cases, SVC devices were integrated into the cases 2et 4 for a better compensation.

Simulation results of these cases are presented in Tables 5, 6, 7, 8 and fig .1,2,3,4.

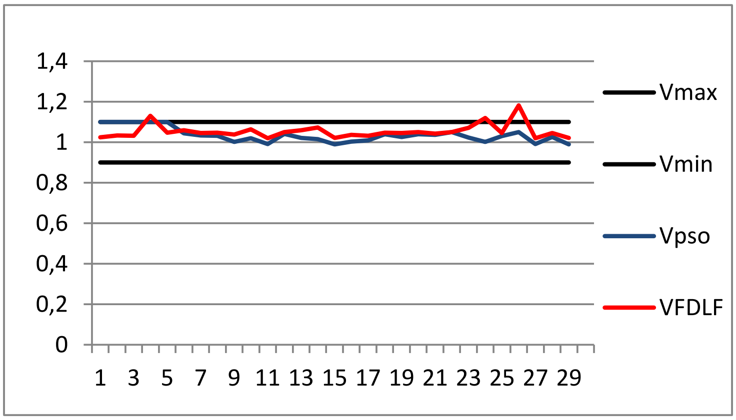

Fig .1. Voltages profiles in the network 60 Kv in case 1

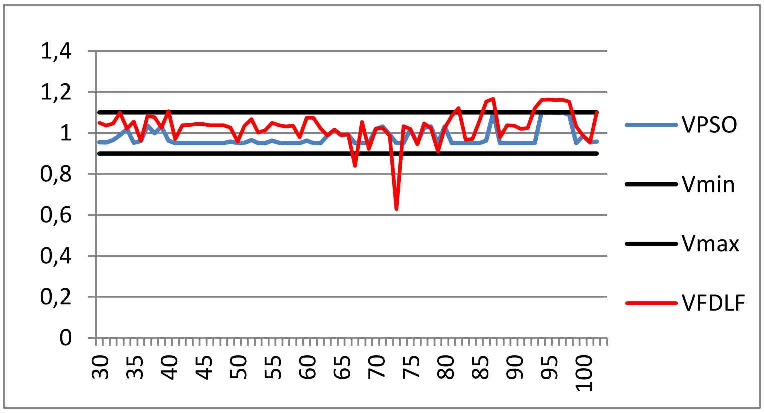

Fig .2. Voltages profiles in the network 400/220 Kv in case 1

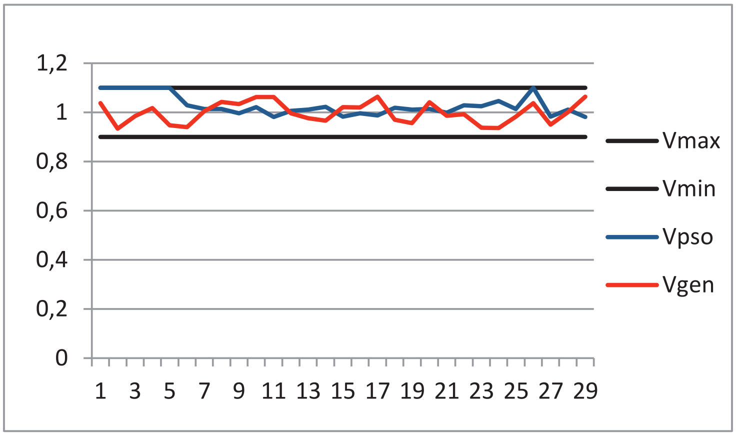

Fig .3. Voltages profiles in the network 60 Kv in case 3 and 4

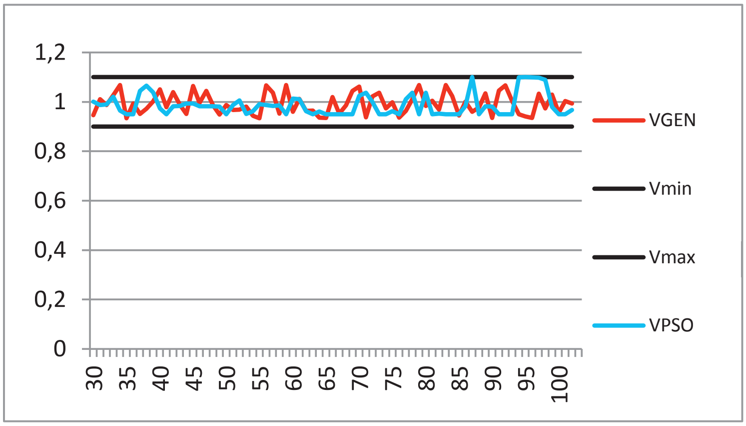

Fig .4. Voltages profiles in the network 400/220 Kv in case 3 and 4

To improve the results several simulations were performed to assess on the voltages and the total active power losses.

Table .5 .Reactive power of generators [Mvar] in case 1 and 2

	Case 2	Case 4
Qg_1	-243.92	-24.11502
Qg_6	-80.09	48.87636
Qg_{12}	75.81	44.61566
Qg_{13}	-35.79	96.4139
Qg_{20}	7.58	164.0643
Qg_{22}	-24.38	30.60451
Qg_{24}	-78.16	147.0771
Qg_{39}	108.25	22.50653
Qg_{51}	-20.56	11.41447
Qg_{55}	6.91	-3.063901

Table .6 . Reactive power of generators [Mvar] in case 3 and 4

	Case 1	Case 3
Qg_1	-272.10	-118.78
Qg_6	-139.11	590.04
Qg_{12}	62.59	41.34
Qg_{13}	39.76	-58.40
Qg_{20}	7.39	-29.71
Qg_{22}	-24.76	66.56
Qg_{24}	-80.64	-77.74
Qg_{39}	181.82	139.29
Qg_{51}	155.77	87.20
Qg_{55}	6.86	-2.09

Table .7. Values of shunt SVC[Mvar] and capacitors in [pu]

	Case 1	Case 2	Case 3	Case 4
Qsvc $_{24}$		6		8.05368
Qsvc $_{26}$		12		15.3889
Qsh $_{38}$	5.00		1.11	
Qsh $_{53}$	10.00		1.10	
Qsh $_{59}$	10.00		1.06	
Qsh $_{60}$	10.00		1.02	
Qsh $_{61}$	10.00		1.03	

Table .8. Total active power loss

	Case 1	Case 2	Case 3	Case 4
Losses [MW]	57.83	51.06	44.93	36.26
Reduction[MW]		6.77	12.90	21.57
Reduction [%]		11.70	22.31	37.30

The obtained results concerning active power losses in the case 4 by the integration of SVCs using GA were better than the case 3 by using shunt capacitors in PSO method. A comparison between case 1 and case 4 shows that this operation optimization also results in a decrease of the total active power losses from 57.83 to 36.26 MW (37.30%).The FACTS (SVCs) controllers are able to change the network parameters in a fast and effective way in order to achieve better system performance.

6. Conclusion

In this study, Genetic algorithm technique and particle swarm optimization approach has been presented to minimise power losses and to improve the voltage profile. This paper demonstrated how the conventional power flow could systematically be extended/modified to include FACTS controllers. This procedure was applied on the 120-bus western Algerian power system using MATLAB software package. The numerical results obtained in our power system indicated an improved performance of GA and PSO. Those results are compared with the basic FDLF program, this one shown that the installation of SVC is able to keep the voltage magnitudes within the pre-specified range and to change significantly the total power losses. Efforts are made to test the performance of the proposed methods to a real power system data which is the western Algerian large power system.

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